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FAILURE ANALYSIS OF A PITCH LINK SELF-LOCKING NUT MS 17825-10

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Abstract: The Aviation and Troop Command (ATCOM) shipped a broken self-locking nut to the Army Research Laboratory-Materials Directorate (ARL-MD) and requested a metallurgical investigation to determine the probable cause of failure. The component was received on 31 October 95. The hexagon shaped, castellated self-locking nut, MS 17825-10, was attached to the lower end of the pitch link located on an army attack helicopter. The outside of the nut contained the manufacturer's designation which consisted of the letter "G" stamped 5 times along a longitudinal section of the part. The nut was fabricated from non-corrosion resistant steel and is to be used at temperatures up to 250°F. During assembly while applying torque, the nut cracked and split open. Further inspection revealed that the nut was cracked at one of the castellations.

Light Optical Microscopy: The self-locking nut received was split open approximately 1/8 of an inch along its longitudinal axis as shown in Figures 1. The cadmium plating was relatively intact with no evidence of general corrosion or pitting observed. The fracture surface contained slight discoloration from post fracture corrosion. This discoloration from corrosion can be seen in Figures 2 and 3. Upon sectioning, it was determined that the crack originated from a slightly subsurface area of the nut near the O.D. as seen in Figures 4 and 5 (arrows denote origin and inclusion band). The radial lines and chevron pattern converge to an area adjacent to the O.D. of the nut opposite the castellated end. A long narrow band was noted on the fracture surface traveling parallel to the O.D. edge of the nut opposite the threads as shown in Figures 2 - 5 (arrows denote band). This region displayed a distinctly different appearance from the remaining fracture. It was deduced that this artifact was a result of an elongated inclusion from primary processing. The inclusion encompassed the entire length of the nut. The fracture likely progressed under uniform loading conditions as evidenced by the lack of distinct crack arrest marks in the origin area. The fracture surface morphology was generally ductile throughout with a considerable amount of inclusions aligned along the longitudinal axis, remnant of the extruding direction of the part. There was a shear lip on the thread tips and on the castellated end of the nut which indicated final fracture.

Metallography: According to the governing specification, MIL-N-25027G, *Nut, Self-Locking, 250 Deg. F, 450 Deg. F, and 800 Deg. F*, the maximum allowance for a defect depth for nuts made from bar or wire with a thread size of 0.625 inches is 0.017 inches as listed in Table VII of that specification entitled Limits of Depths on Laps, Seams, and Inclusions. Also contained in that specification, is "Figure 2" entitled Acceptable and rejectable defects of self-locking nuts as revealed by magnetic particle or fluorescent penetrant inspection. This figure shows that laps or seams that intersect an edge in line with beam slots (castellations) passing through the center of the hex flats are rejectable.

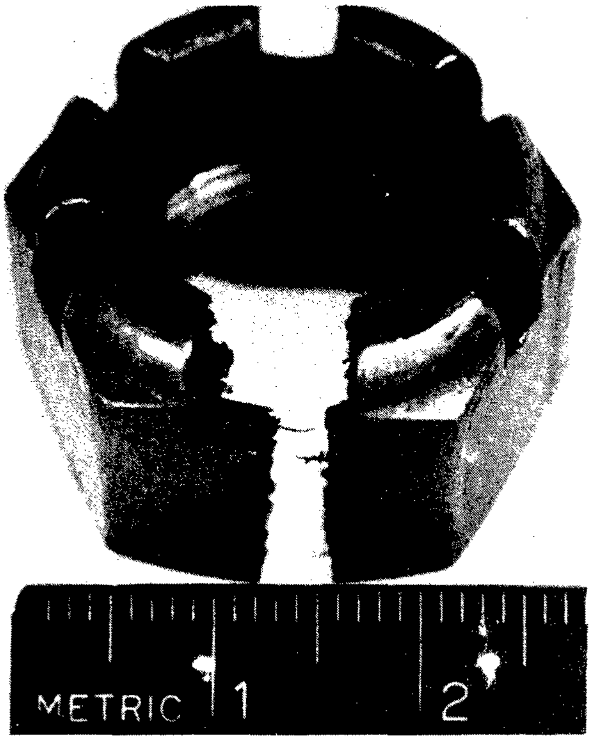

Figure 1. As received condition of failed component, scale in centimeters.

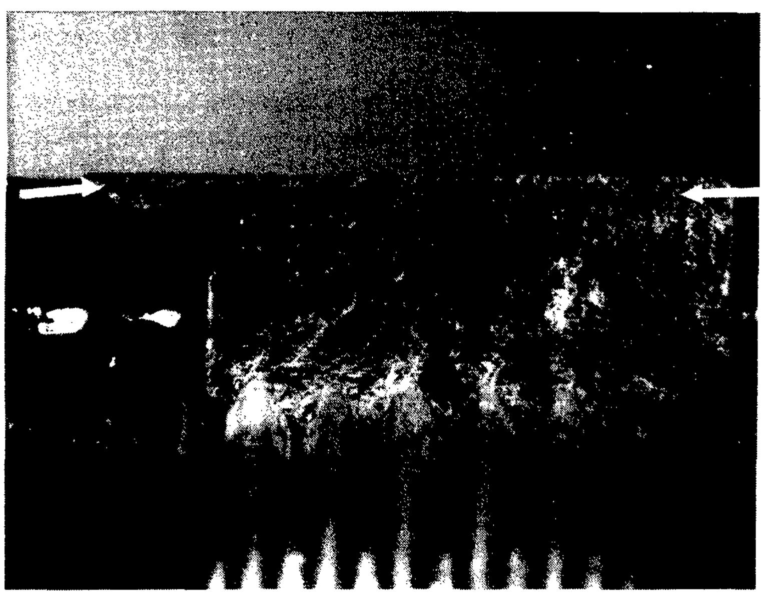
Figure 2. Micrograph of fracture half "A" showing corrosion. Mag. 10x

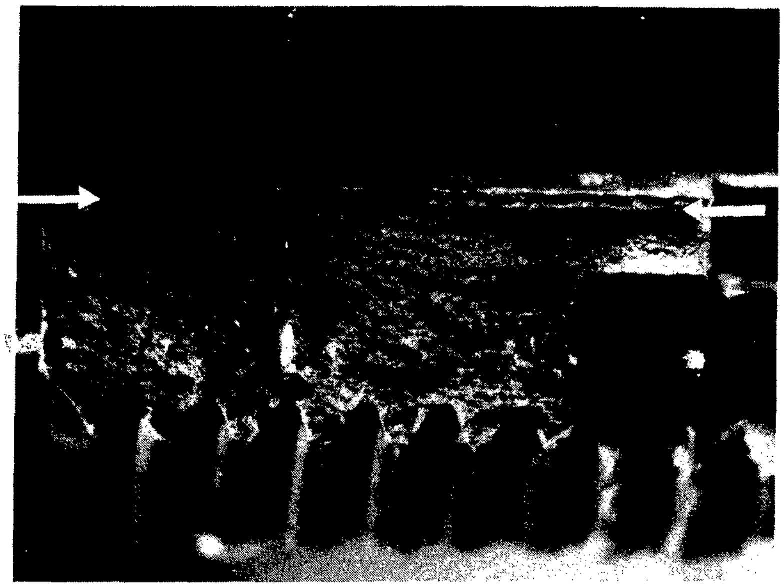

Figure 3. Micrograph of fracture half "B" showing corrosion. Mag. 10x

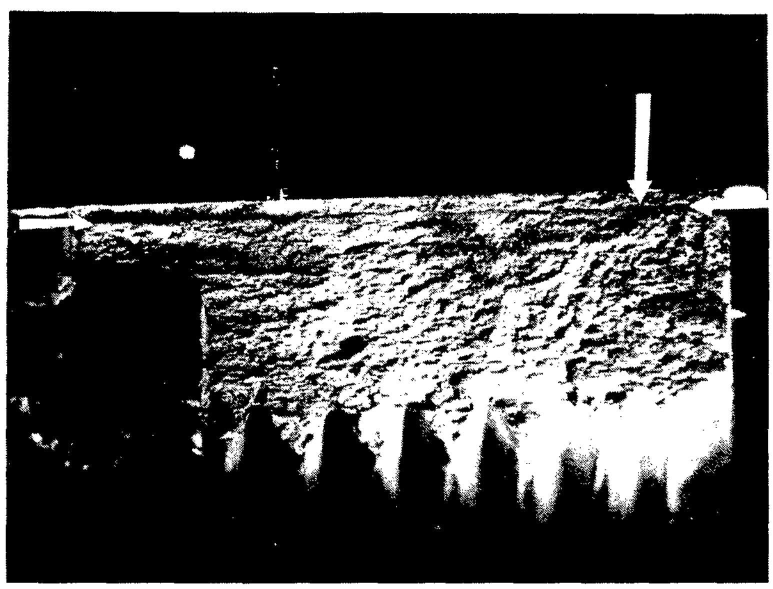

Figure 4. Micrograph of fracture half "A", arrow denotes origin. Mag. 10x

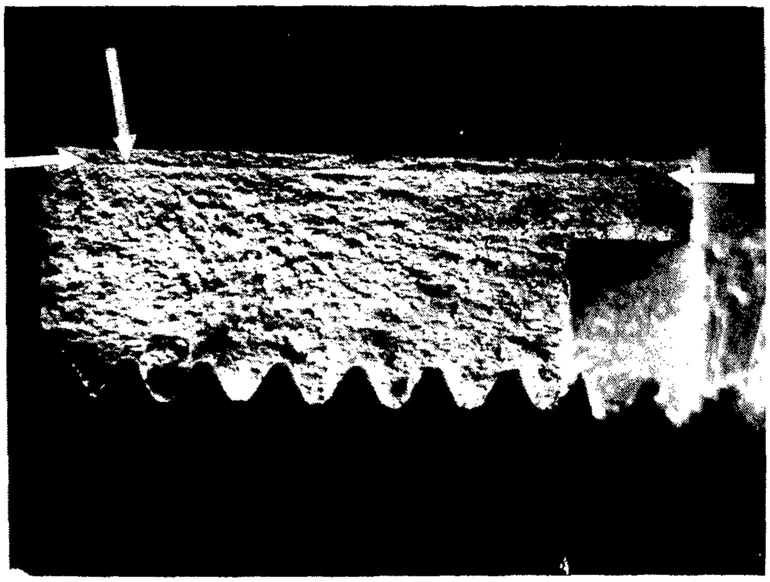

Figure 5. Micrograph of fracture half "B", arrow denotes origin. Mag. 10x

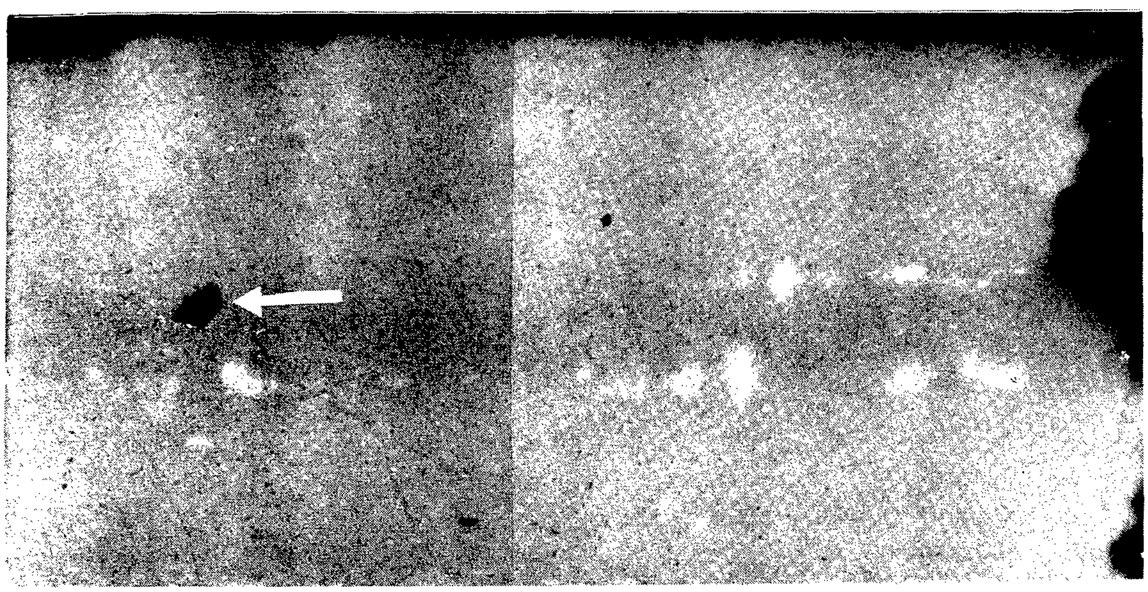

Figure 6. Micrograph of failure inclusion size and depth. Mag. 200x

The failed part has a thread size of 0.625 inches and therefore falls under the above criteria. A cross-section of the inclusion from the failed part can be seen in Figure 6. This section was taken from an area 0.025 inches from the fracture surface at the end opposite the origin. The inclusion depth at this location is 0.010 inches as measured from the photomicrograph per ASTM-B-487. This is within the limit set forth in MIL-N-25027G. It is important to note that the governing specification is probably not referring to inclusions of the type that caused this failure in setting the limits on depth. The specification is most likely referring to abnormalities or discontinuities open to the surface that can not be labeled as laps or seams. Inclusions of this severity are indeed rare since proper primary processing techniques usually eliminate them. The maximum depth of this inclusion was contained on the fracture surface and can be seen in the Scanning Electron Microscopy section of this report. Mn-S stringer inclusions are very common in steels of this type, however the inclusion that caused this failure was approximately 100 times larger in cross sectional area than normal inclusions of the same type.

The microstructure of the nut was further investigated. There was no cleanliness rating or inclusion content limit found within the governing specification. However, the other inclusions within the nut matrix were large and numerous. Although not required, the measure of cleanliness for this material was a type A (sulfide type) level 5, the worst, according to ASTM-E-45 entitled <u>Chart for Determining the Inclusion Content of Steel</u>. A tempered martensitic lathed structure was noted which was consistent with the prior heat treatment for this material.

Chemical Analysis: Chemical analysis was performed to determine which one of the four prospective alloys (AISI 1137, 11L37, 4130, 8740) was utilized in the fabrication of this component. A section of the nut was subjected to atomic absorption and inductively coupled argon plasma emission spectroscopy. The carbon and sulfur contents were analyzed by the LECO combustion method. Results of the analysis showed the nut compared most favorably with alloy 11L37, as shown in Table I. The carbon content of the material was out of specification as it was more than 0.1% higher than the requirement of 0.32 - 0.39%. Having a higher carbon content in steels can lead to deleterious effects in the mechanical properties of the material.

Table I
Chemical Composition of the Pitch Link Nut
Weight Percent

Element	Component	1137	11L37	4130	8740
Carbon	0.50	0.32-0.39	0.32-0.39	0.28-0.33	0.38-0.43
Manganese	1.42	1.35-1.65	1.35-1.65	0.40-0.60	0.75-1.00
Phosphorus	0.012	0.04 max.	0.04 max.	0.025 max.	0.025 max.
Sulfur	0.108	0.08-0.13	0.08-0.13	0.025 max.	0.025 max.
Silicon	0.05	*	*	0.15-0.35	0.15-0.35
Chromium	0.05	*	*	0.80-1.10	0.40-0.60
Nickel	0.02	*	*	0.25 max.	0.40-0.70
Molybdenum	<0.01	*	*	0.15-0.25	0.20-0.30
Lead	0.2	*	0.15-0.35	*	*
Iron	balance	balance	balance	balance	balance

* - Not listed with specification

Mechanical Properties:

Surface Roughness Measurements

The surface roughness of the component was verified by a Mitutoyo Surftest 401 analyzer. Readings were measured on the exterior surface of the nut in both the longitudinal and transverse directions. Specification MS 17825 requires the nut have a surface finish of 125 µin. or smoother. Each of the ten readings met this requirement, as shown in Table II.

Table II
Surface Roughness Measurements, µin

Transverse	Longitudinal
69	50
74	46
78	54
69	40
54	61
MS 17825	125 µin

Hardness Testing

Hardness testing was performed on a mounted and polished cross-section of the nut. Testing was conducted even though specification MS 17825 does not require hardness nor ultimate tensile strength. The Rockwell "A" scale was utilized, due to the light major load (60 kg) which allowed for more readings on the sectioned surface. A total of ten readings were taken on a longitudinal and transverse section of the nut. The results are listed in Table III.

Table III
Hardness Testing Rockwell "A" Scale
60 kg Major Load

Transverse	Longitudinal
67.4	66.0
67.5	64.5
67.7	64.7
67.8	65.8
67.3	65.2
Average	66.4

Scanning Electron Microscopy and Energy Dispersive Spectroscopy: The fracture surface of the failed nut was characterized utilizing Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS). The surface, with the exception of origin area and the inclusion that caused the failure, was composed entirely of ductile dimples (D) with elongated stringers characteristic of an overload failure of an extruded part. The fracture surface is shown in Figure 7, note the inclusion band that caused failure denoted by arrows. Figure 8 shows the origin area (arrow denotes origin). It can be observed at higher magnification in Figure 9 and 10. The Mn-S stringer

Figure 7. SEM fractograph of the nut, arrows denote line of inclusions. Mag. 10x

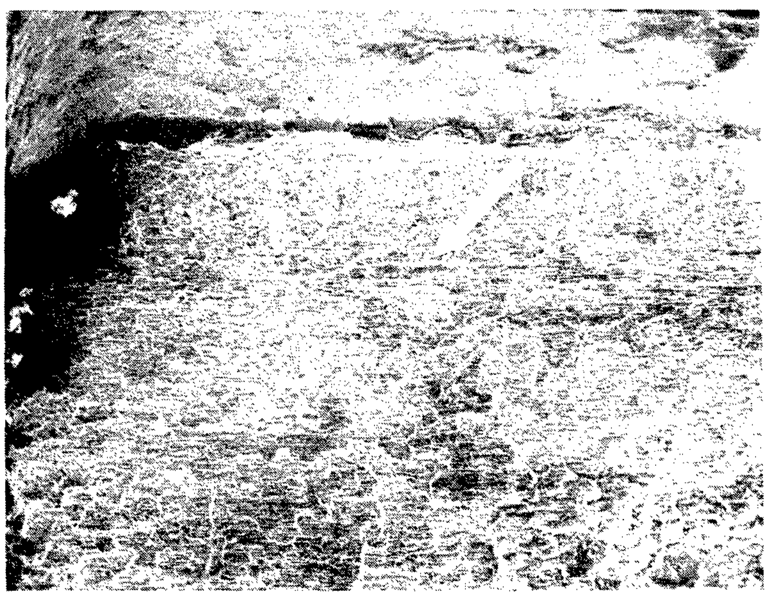

Figure 8. SEM micrograph of the origin area, arrow denotes origin. Mag. 75x

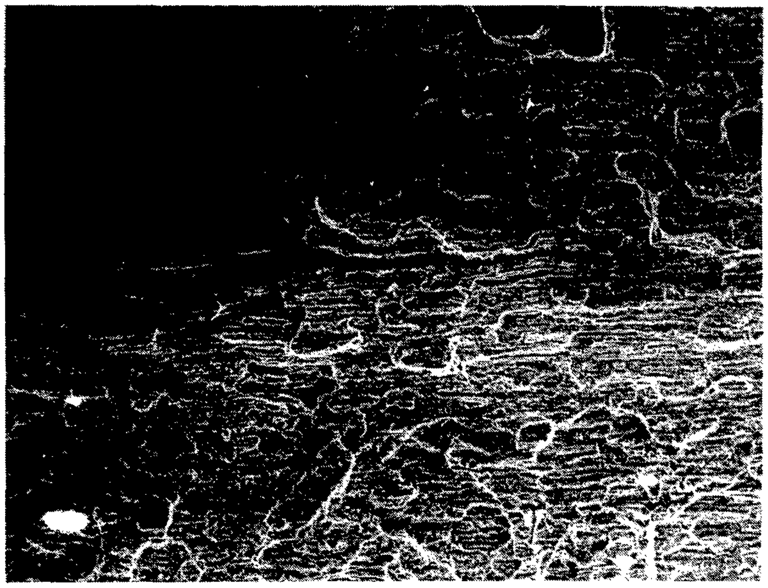

Figure 9. SEM micrograph of the inclusion that caused failure. Mag. 200x

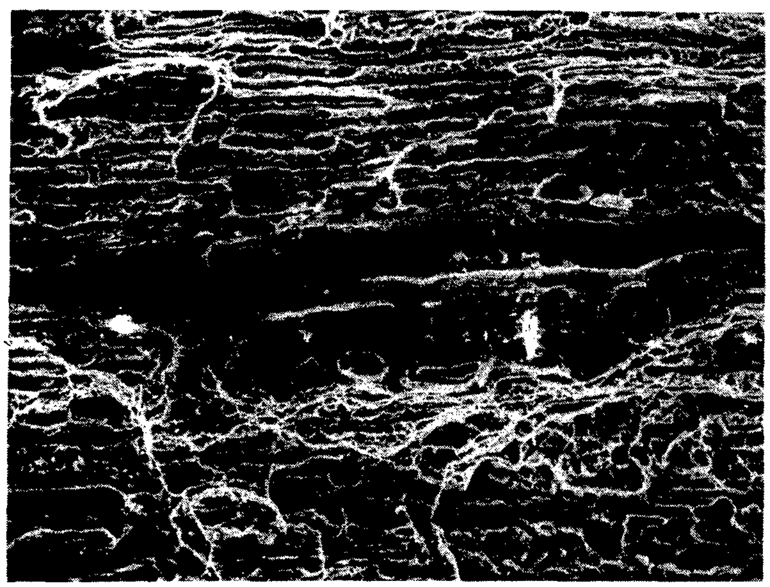

Figure 10. SEM micrograph showing Figure 9 at high magnification. Mag. 500x

that caused this cavity was not present at the origin but the inclusion must have measured at least 0.0015 inches in diameter as is approximately 0.013 inches in depth from the surface. Fracture morphology near the origin was mixed-mode, both transgranular (T) and ductile (D) modes of fracture are shown in Figure 11. Cadmium rich areas were found along the Mn-S stringer that caused failure indicative of a path open to the outside surface may have existed while the nut was in the plating bath. These cadmium deposits are shown in Figure 12 denoted by arrows. Figure 13 depicts the fracture surface morphology of the majority of the nut and the ductile dimples aligned along the extrusion direction. Shear lips (SL) were also noted on the tips of the threads and the castellated end indicating that these areas were the last to fail. The fracture morphology of the shear lips is shown in Figure 14. The inclusions on the fracture surface were identified to be manganese-sulfide through Energy Dispersive Spectroscopy (EDS) utilized in conjunction with the SEM. Inclusions of this severity can be deleterious to the mechanical properties of the material. Inclusions of the magnitude of the one causing this failure may obviously be catastrophic to the component. Figure 15 maps out the entire fracture surface morphology indicating the respective fracture modes. EDS aided in determining the fact that the inclusion band contained cadmium. This provided evidence that the defect may have been open to the surface during the cadmium plating process and occurred as a result of primary processing operations as opposed to a service or installation related anomaly. The use of EDS also helped identify that the nut contained lead as verified by chemical analysis.

Failure Scenario: The MS 17825-10 self-locking nut that secures the lower end of the pitch link failed by overload. This failure was the result of a large inclusion which was located slightly subsurface between beam slots or castellations on the nut. The crack progressed by one or by very few high loading cycles until final fracture occurred. The failure was also assisted by the low degree of "cleanliness" due to the other numerous elongated inclusions within the matrix of the material. The nut failed while applying torque and installation loads due to the existence of the defect. Evidence substantiating this scenario is the fact that the crack origin was determined to be at the base of this defect, the cadmium found within the defect, the mixed mode of fracture at the origin, the overall ductile mode of fracture, and the lack of crack arrest marks emanating outward from the inclusion that caused failure.

Conclusion: The failure of the MS 17825-10 Pitch Link Self-Locking Nut that secures the lower end of pitch link on the helicopter was the result of an inherent material defect. A large (0.0015 inch diameter) subsurface Mn-S inclusion caused the component to fracture during installation. Cracking originated along the base of the subsurface flaw approximately 0.015 inches below the surface. The inclusion may have been exposed to the outside surface of the nut due to the presence of cadmium within the flaw, although a direct path could not be found. The crack progressed by overload along the longitudinal axis of the nut. Crack propagation was aided due to the size and length of this inclusion and the significant amount of other Mn-S stringers within the material.

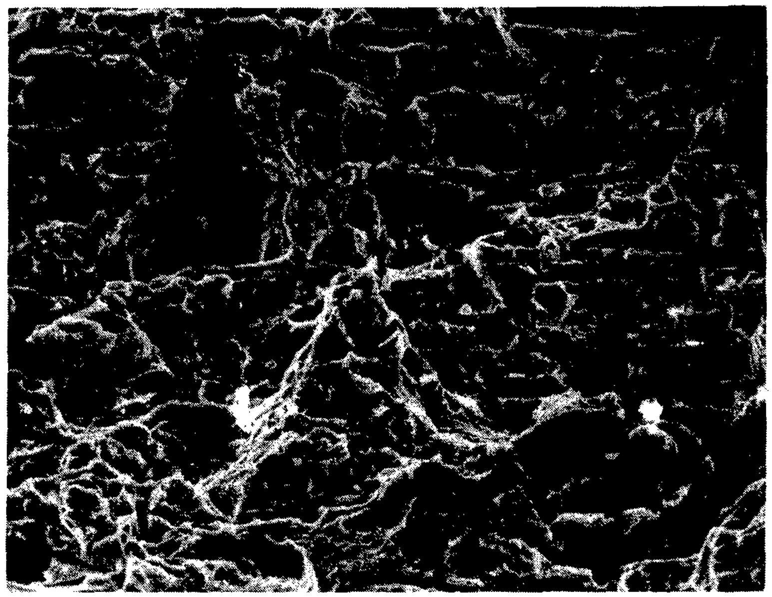

Figure 11. SEM micrograph of transgranular-ductile morphology at origin. Mag. 1000x

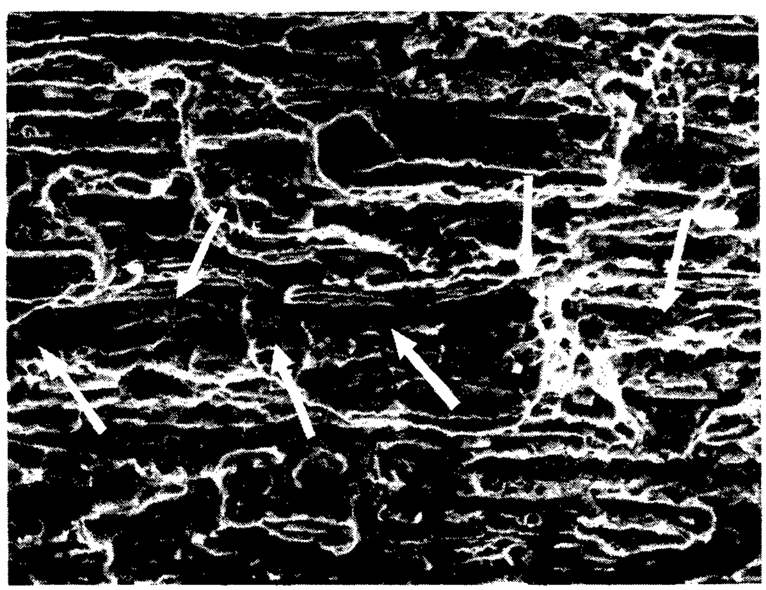

Figure 12. SEM micrograph of cadmium line along inclusion line. Mag. 1000x
Arrows denote existence of cadmium.

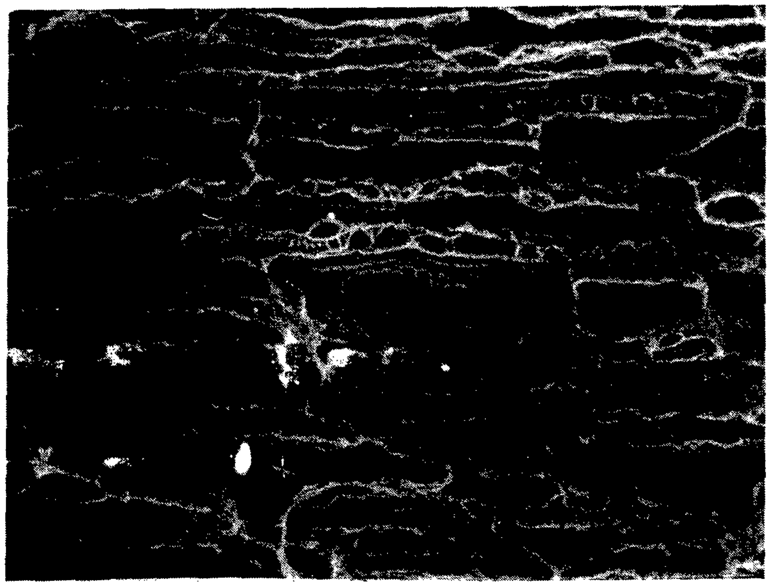

Figure 13. SEM micrograph of the elongated ductile morphology. Mag. 1000x

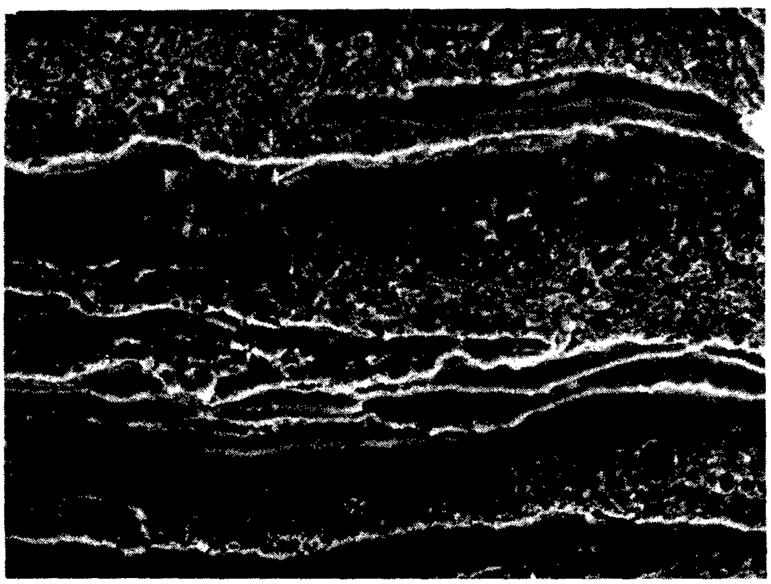

Figure 14. SEM micrograph of the morphology of the shear lip region. Mag. 1000x

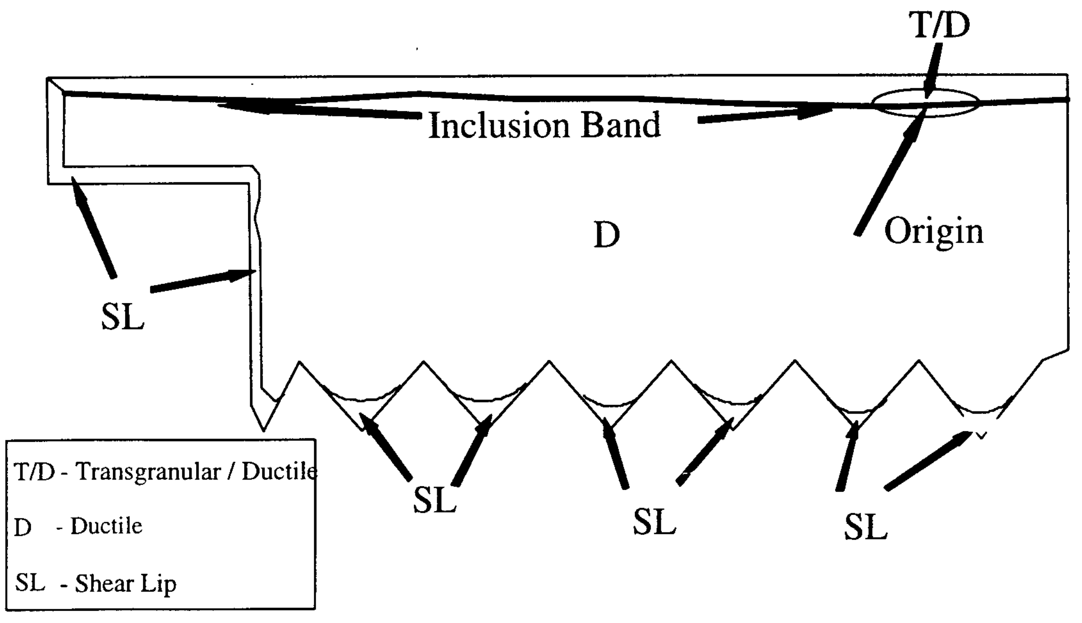

Figure 15. Map of fracature surface morphology for the failed component.